LOAD REDUCTION (ARCHING) ON BURIED RIGID CULVERTS USING GEOFOAM: LONG-TERM BEHAVIOUR

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Abstract: Three instrumented full-scale tests using geofoam (expanded polystyrene) for load reduction on buried rigid culverts are described. The culverts were built and instrumented in the period from 1988 to 1990. The method involved installing a compressible inclusion (geofoam) above rigid culverts in order to reduce the vertical earth pressures. The first instrumented culvert was a concrete pipe with diameter of 1.95 m beneath a 14 m high rock-fill embankment. The second full-scale test was a concrete pipe with diameter of 1.71 m beneath a 15 m high rock-fill embankment. The third instrumented structure was a concrete box culvert with width of 2.0 m beneath 11 m of silty clay. The instrumentation included vertical and horizontal earth pressure, deformation and temperature measurements. The geofoam effectively reduced the vertical earth pressures. The long-term observations showed that the earth pressures were reduced to less than 30% of the overburden in the granular fill and reduced to less than 50% of the overburden in the silty clay. The long term observations of earth pressures and deformations for more than 15 years showed that the method using geofoam is stable over time.

Keywords: EPS geofoam, full-scale test, instrumentation, earth pressure, deformation

INTRODUCTION

The earth pressure on deeply buried culverts is significantly affected by arching. Both the magnitude and distribution of earth pressure on buried culverts are known to depend on the relative stiffness of the culvert and the soil. The so-called induced trench method (also called imperfect ditch) involves installing a compressible layer above the rigid culvert. As the embankment is constructed, the soft zone compresses more than the surrounding fill, and thus induces positive arching above the culvert. Organic material (sawdust, hay, leaves) has traditionally been used as the compressible material (Spangler 1958, Sladen and Oswell 1988, McAffee and Valsangkar 2005).

Terzaghi (1943) stated that the amount of arching can only be obtained by direct measurement under field conditions. Kang *et al.* (2007) concluded that the long-term effects on induced trench performance need to be studied further. Three instrumented field installations consisting of two concrete pipes and one cast-in placed box culvert were built in Norway in the period from 1988 to 1990.

Years later, this method using geofoam to reduce earth pressure was also used on concrete culverts below high fills in China (Yang *et al.* 2005 and Zhang *et al.* 2006).

INSTRUMENTED FIELD INSTALLATIONS

Field installation at Eidanger

The first field installation built in 1988 was a concrete pipe with diameter 1.71 m beneath a 15 m high rock-fill embankment. Standard EPS blocks 0.5 m x 1.0 m x 2.0 m were used. Six test specimens of EPS were tested in the laboratory, and showed an average compression strength of 98.3 kPa. The measured density was 20.3 kg/m^3. The EPS blocks were placed when the backfill was 0.5 m above the top of the pipe. The placement of the blocks was very fast and simple, and no excavation of a ditch above the pipe was needed.

The in-situ soil was excavated to about 0.5 m below the culvert elevation, down to bedrock, and replaced by 0-16 mm sandy grave1. The same material (0-16 mm sandy gravel) was used for backfill, with an optimum dry density of 21.5 kN/m^3 and optimum moisture content of 9.3 %. A minimum of 97 % Standard Proctor compaction was required. Field density tests showed an average of 100 % Standard Proctor compaction (15 tests). The backfill was compacted in 20 cm thick layers. The pipe with the depth of the backfill zone and the instrumentation arrangement is shown in Figure 1.

The backfill extended 1 m away from spring line and 0.5 m over the top of the pipe. The remaining fill in the embankment was rock-fill that was placed in 3 m thick layers, and compacted with 6 to 8 passes with a 6 ton vibratory roller. Based on field experience, this equates to 95-97 % Standard Proctor compaction. The construction began in August 1988 and was completed in June 1989.

To evaluate the performance of the pipe and the EPS during construction and on a long-term basis, the pipe and the surrounding backfill were instrumented with Gloetzl hydraulic earth pressure cells. In addition, settlement tubes were installed on top of the pipe and on top of the EPS to measure vertical deformation. The dimensions of the Gloetzl cells were 20x30 cm, and 4 cells were used. The location of the cells is shown in Figure 1. Cell 1 was placed on spring line to measure the horizontal earth pressure on the pipe. Cells 2 and 3 were placed 20 cm over the top of the pipe to measure the vertical earth pressure, with cell 2 above the centreline, and cell 3 above the spring line (cell 3). Cell 4 was placed 2m above the top of the pipe along the centre line to measure the vertical earth pressure in the embankment. The temperatures in the soil at the cell locations were measured with thermistors, and temperature corrections were applied. Earth pressure and deformation measurements during construction are described in Vaslestad (1991).

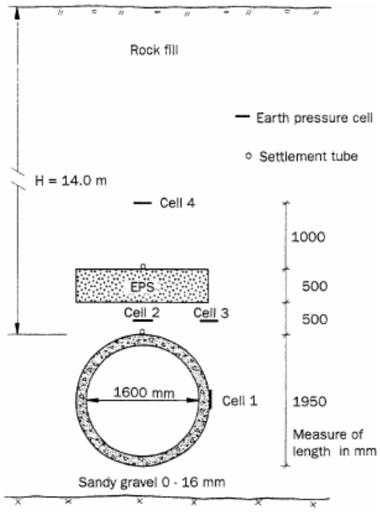

Figure 1. Instrumentation arrangement at Eidanger

The earth pressure measured in cell 2 at the top of the pipe is shown in Figure 2. The measured earth pressure increased to 72 kPa in September 1988 when the fill height was 8.3 m. Additional increased in the fill height to 13.7 m did not increase the earth pressure. In the period from 1996 until January 2008, the earth pressures on the top of the pipe were relatively constant about 66 to 68 kPa, which was 25 % of the overburden.

The earth pressure recorded in cell 3 at the end of construction was 161 kPa (see Figure 2). The earth pressure only varied between 161 kPa and 167 kPa in the next period of twenty years. The values were 61 to 63 % of the overburden. Since only half of cell 3 was covered with EPS, it explained the higher earth pressure measured compared to cell 2.

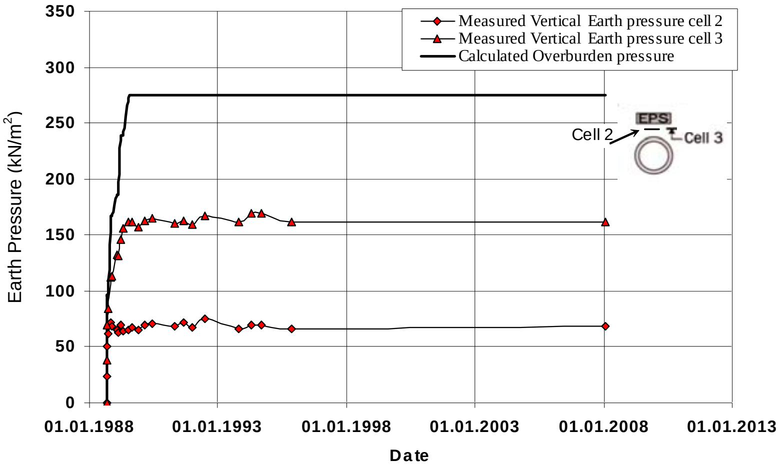

Figure 2. Measured earth pressures in cells 2 and 3 at Eidanger

The measured horizontal earth pressure on the pipe spring line (cell 1) is shown in Figure 3. The earth pressure at the end of construction was 164 kPa. The earth pressures increased slowly. After almost twenty years, the horizontal earth pressure was 211 kPa. This was 72 % of the overburden. The horizontal earth pressure was 3 times higher than the measured vertical earth pressure on top of the pipe. This is not desirable and shows that it is necessary to increase the width of the EPS to decrease the horizontal earth pressure to a value approximately equal to the vertical earth pressure. In spite of the relatively large horizontal earth pressure, the pipe showed no sign of distress.

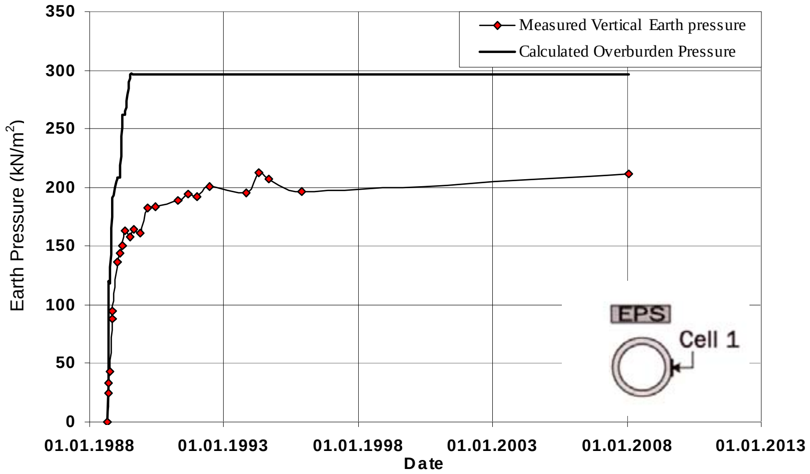

Figure 3. Measured earth pressures in cell 1 at Eidanger

The earth pressure recorded in cell 4 above the EPS is shown in Figure 4. The earth pressure was 204 kPa at the end of construction, and increased to 222 kPa after almost 20 years.

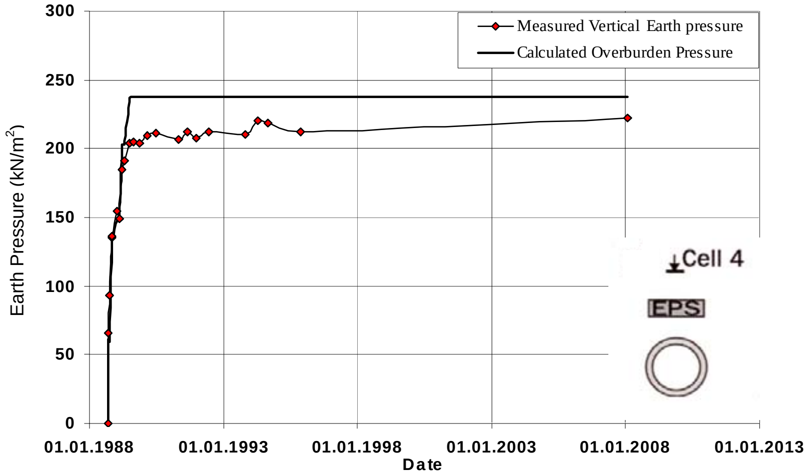

Figure 4. Measured earth pressures in cell 4 at Eidanger

The measured vertical compression of the EPS is shown in Figure 5. The vertical deformation stabilised after several years with about 140 mm compression, and there was no further increase for almost 20 years. This deformation was 28% of the initial thickness of the EPS.

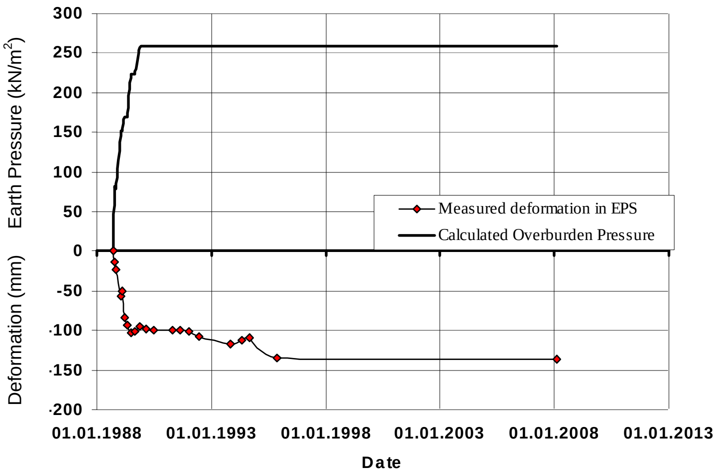

Figure 5. Measured deformations of the expanded polystyrene at Eidanger

Field installation at Sveio

The culvert was a concrete pipe with inner diameter of 1.4 m and outer diameter of 1.71 m. The embankment above the pipe consisted of 15 m of rock-fill. Based on the experience from the first field installation at Eidanger and parameter studies with the CANDE-program (Vaslestad *et al.* 1993), the width of the compressible layer was increased to at least 1.5 times the outer diameter of the pipe. Increasing the width of the EPS to 1.5 times the width of the pipe has a positive effect on the structural response of the pipe. It decreased the horizontal earth pressures on the pipe. This is also in accordance with the findings of Sladen and Oswell (1988). The ideal condition is that the horizontal earth pressure should approximate the vertical earth pressure .

For practical reasons, the width of the EPS was 3.0 m and blocks with thickness of 0.5 m was used. The compression strength of the EPS was 100 kPa and density 20 kg/m^3. The in-situ soil consisted of dense moraine and well-graded sandy gravel with thickness of 400 mm was used as the foundation.

The well-graded sandy gravel (0-16 mm) was also used for the backfill. The backfill was compacted in 20 cm thick layers and nuclear field density tests showed an average of 98.5 % Standard Proctor compaction. The backfill extended 1 m out from the spring line and 0.5 m above the EPS. The remaining fill in the embankment was rock fill. The average unit weight of soil (γ) was 20 kN/m^3. The construction began in November 1989 and the embankment reached 13.7 m above the pipe by February 1990. The remaining fill was placed in the beginning of 1992. The pipe and the backfill were instrumented with 5 Gloetzl hydraulic earth pressure cells. Two settlement tubes were installed on top of the EPS to measure the vertical deformation. The instrumentation arrangement is shown in Figure 6.

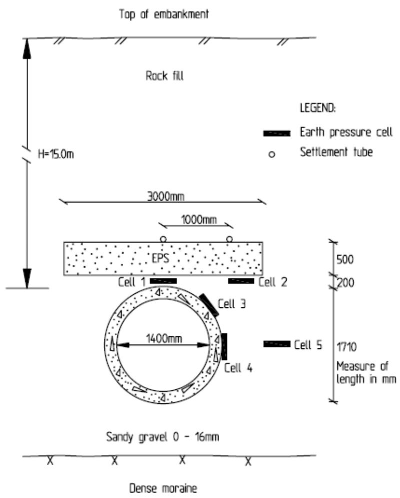

Figure 6. Instrumentation arrangement at Sveio

The measured earth pressures in cell nos. 1, 2 and 3 are shown in Figures 7 and 8. The earth pressure measured in cell 1 at the top of the pipe was 75 kPa when the fill reached 15 m above the pipe. In February 2008, the earth pressure was 74 kPa. This was 25 % of the overburden. The earth pressure recorded in cell 2 was slightly larger, while the earth pressure in cell 3 were 96 to 97 kPa during this period (see Figure 8).

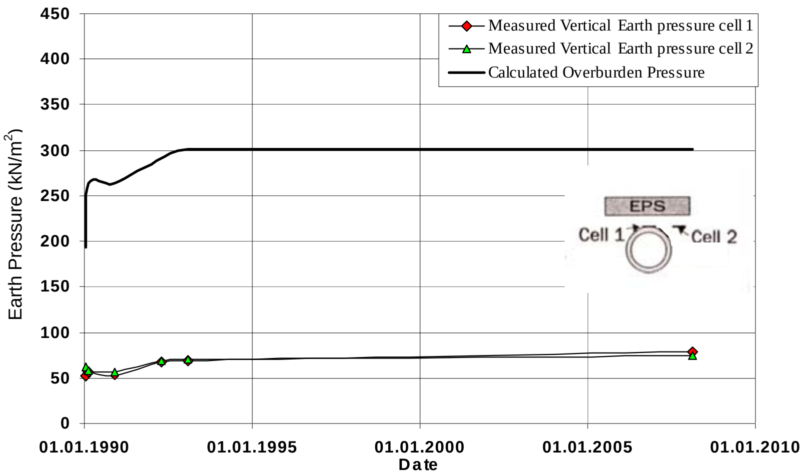

Figure 7. Measured earth pressures in cells 1 and 2 at Sveio

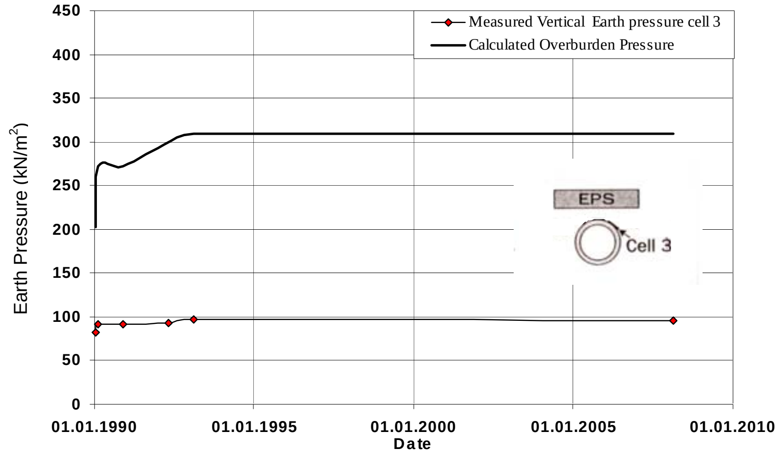

Figure 8. Measured earth pressures in cell 3 at Sveio

The horizontal and vertical earth pressures on the pipe spring line (cells 4 and 5) are shown in Figure 9. The horizontal earth pressure was 45 kPa after full fill height, and increased to 49 kPa in the next 15 years. The vertical earth pressure at the same level (cell 5) was 170 kPa after the end of construction and increased to 191 kPa after 15 years. The average measured horizontal earth pressure coefficient (K) was 0.27 at the pipe spring line. Compared to the measured vertical earth pressure at the top of the pipe, the average horizontal earth pressure was around 70 %. This implies that the moments in the pipe are very small. This shows that increasing the width of the EPS reduces the horizontal earth pressure.

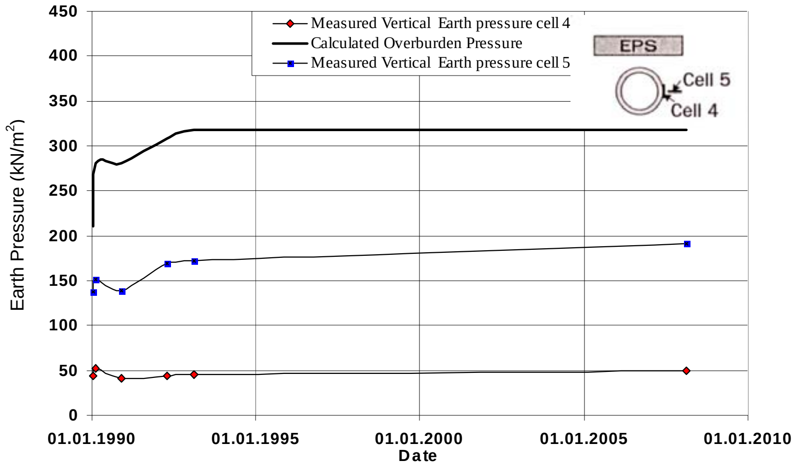

Figure 9. Measured earth pressures in cells 4 and 5 at Sveio

The measured vertical compression of the EPS is shown in Figure 10. The deformation was 65 mm at fill height of 12 m and increased to 88 mm at fill height of 13.7 m. When the remaining fill up to 15.0 m was placed, the deformation increased to 131 mm.. The next measurements after 15 years showed that the deformation has increased to 190 mm. This was 38 % of the initial 50 cm thickness of the EPS.

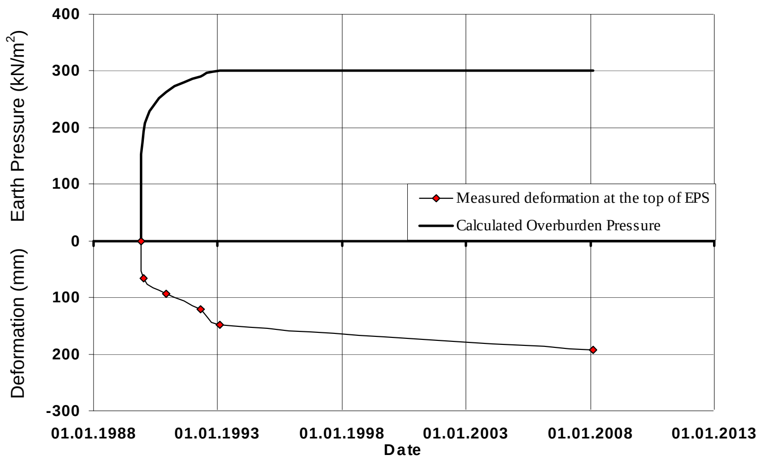

Figure 10. Measured deformations of the expanded polystyrene at Sveio

Field installation at Hallumsdalen

The culvert was a cast-in-place box culvert with width of 2.0 m and height of 2.55 m. It was a continuous culvert and has a total length of 385 m. It crossed a valley beneath an embankment of compacted dry crust clay up to 23 m in height. The subsoil consisted of over-consolidated silty clay with water contents of 25% to 30 % and undrained shear strengths of 35 to 70 kPa.

To investigate the time effects on the earth pressures in the cohesive fill using the imperfect ditch method, the expanded polystyrene was placed above the culvert with length of 20 m. The instrumented section of the culvert was situated in the silty clay counter fill. The unit weight of the silty c1ay (γ) was 20 kN/m^3. The expanded polystyrene with thickness of 0.5 m and width of 2.0 m was placed above the culvert as shown in Figure 11. The section was instrumented with two Gloetzl hydraulic earth pressure cells (cells 1 and 2). The deformation of the EPS was measured using a settlement plate. Cells 1 and 3 were placed at different cross-sections above the culvert to compare the earth pressures of the imperfect conventional ditch section with and without EPS, respectively (see Figure 11).

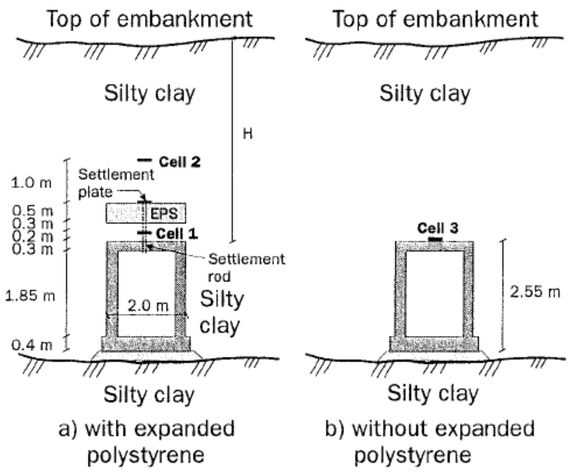

Figure 11. Instrumented arrangement at Hallumsdalen

The construction of the embankment began in July 1989. The measured earth pressures in cell 1 at the top of the culvert are shown in Figure 12. At completion of the fill in February 1990, the fill height was 10.8 m above the ce11 level and the overburden was 206 kPa. The measured earth pressure was 132 kPa at this fill height, which was 63 % of the overburden. The earth pressure decreased slightly to 123 kPa in April 1991. There was a further decrease to 88 kPa in December 1991. This was probably due to stability problems and movements in the counter fills that occurred in April 1991. The earth pressure stabilised to about 100 kPa in 1993. The last measurement in July 2007 showed the earth pressure of 92 kPa.

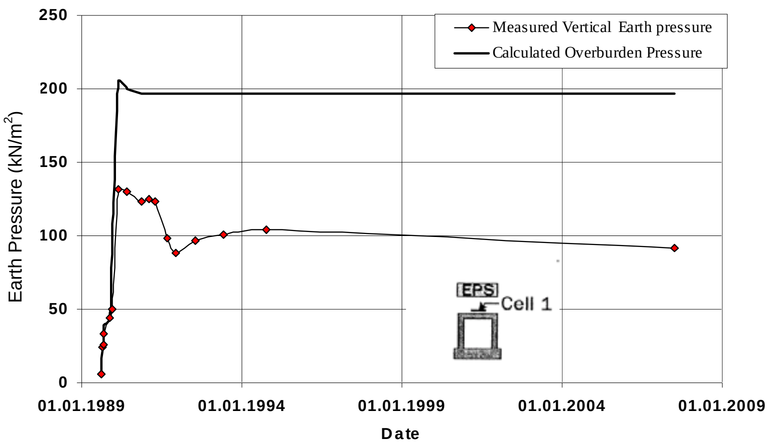

Figure 12. Measured earth pressures in cell 1 at Hallumsdalen

The measured earth pressures in cell 2, which was located in the fill 1 m above the EPS, are shown in Figure 13. At completion of fill in February 1990, the earth pressure was 144 kPa, which was 81 % of the overburden. The earth pressure decreased to 128 kPa in July 1992 and further reduced to 110 kPa in July 2007.

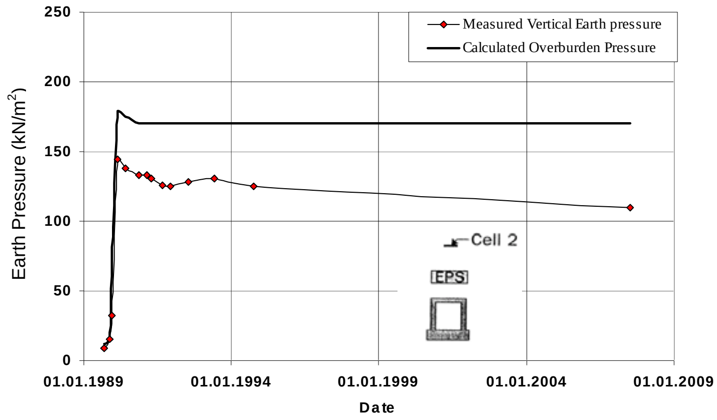

Figure 13. Measured earth pressures in cell 2 at Hallumsdalen

The earth pressures in cell 3, which was located on top of the culvert in a section without EPS, are shown in Figure 14. The fill height above the culvert was 9.8 m. At completion of the fill in February 1990, the measured earth pressure was 244 kPa. The overburden was 196 kPa, and the measured earth pressure was 1.24 times the overburden. Based on extensive finite element modelling, Tadros *et al.* (1989) proposed an expression for calculating the earth pressures on concrete box culverts. For silty clay soil, their expression gives an earth pressure of 1.17 times the overburden on top of the culvert. The measured earth pressure was 245 kPa in July 2007.

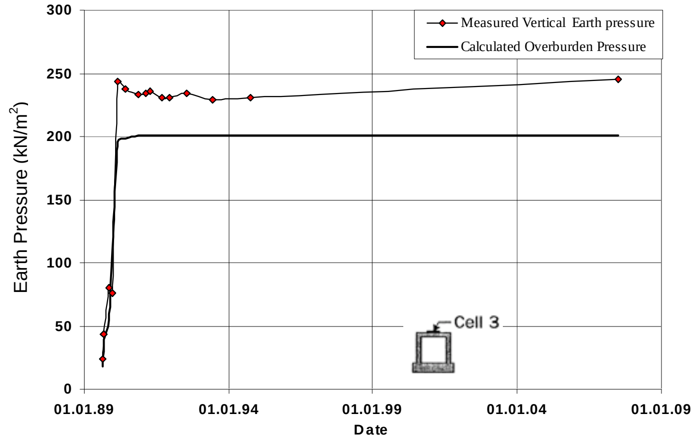

Figure 14. Measured earth pressures in cell 3 at Hallumsdalen

The measured deformations of the EPS are shown in Figure 15. The deformation was 60 mm when the overburden was 100 kPa, which corresponded to the compression strength of the EPS. The deformation was 220 mm at the completion of the fill, when the overburden was 196 kPa. For the next four years, the deformation slightly increased to 250 mm, which was 50 % of the initial thickness of the EPS. The last measurement in July 2007 showed an increase to 269 mm, which was 54 % of the initial thickness. This showed that the deformation of the EPS in cohesive fill is greater than in granular fills. The observed settlements of the culvert were between 70 and 110 mm in the instrumented sections during the observation period.

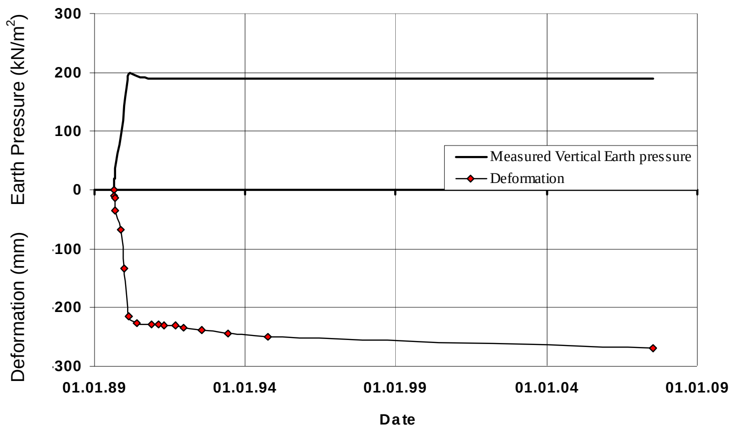

Figure 15. Measured deformations of the expanded polystyrene at Hallumsdalen

CONCLUSIONS

The long-term full scale tests showed that the induced trench method can be used to reduce the vertical earth pressure on rigid culverts. The expanded polystyrene blocks that are used as the compressible material, are super light, easy to handle, and they simplify the construction procedure. The use of organic material in induced trench culverts is not recommended due to the possibility of decomposition and the difficulty of specifying the material characteristics. The two full scale tests on concrete pipes backfilled with well compacted sandy gravel beneath high rock-fills showed that the vertical earth pressures on top of the pipes were reduced to less than 30 % of the overburden. The long-term compressions of the expanded polystyrene varied from 28 to 38 %. Long-term measurements showed that there were no marked increases in vertical earth pressures after the end of construction. Based on the full scale tests and finite element analyses, it is recommended to use expanded polystyrene of width at least 1.5 times the outer diameter of the pipe. One full-scale test on a concrete box culvert backfilled with silty clay and situated below a silty clay embankment was performed. Sections with and without expanded polystyrene were instrumented. The vertical earth pressure in the section with expanded polystyrene was reduced to less than 50 % of the overburden. The vertical earth pressure on the section without expanded polystyrene was 1.24 times the overburden. The measured long-term compression of the expanded polystyrene was 54 % of the initial thickness of 50 cm. The instrumentation also showed that the hydraulic earth pressure cells are still working after almost 20 years. Long-term arching on flexible steel culverts was also measured with hydraulic earth pressure cells for a period of 21 years by Vaslestad *et al*. (2007).

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